Optimizing Your Breast MRI Technique

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Introduction

Breast magnetic resonance imaging (MRI) is finding wider application in the clinical management of breast cancer and both the technology and performance standards for breast MRI continue to improve. In 2003, the American College of Radiology (ACR) added MRI and ultrasound to its publication of the ACR BIRADS® Breast Imaging Reporting and Data System [1], providing guidelines for performing and interpreting breast MRI. Developments in breast coil technology, biopsy equipment and CAD systems are all contributing to improved utilization of breast MRI. In the following review, we discuss the technical aspects of breast MRI and consider some of the clinical indications that are emerging.

Technical considerations for optimizing your breast MRI technique

Equipment

To date, breast MRI has been performed mostly on 1.5 T magnets because of the widespread availability of these systems. A limited number of studies have been reported at lower field strengths, but the available published data are inadequate to make a true comparison of performance [2-4]. The signal-to-noise advantage of higher field strengths is presumed to translate into better ability to detect breast cancers, but this has not been established. Another advantage of higher field strength is the greater spectral separation attainable, leading to more robust fat-suppression and better ability to resolve individual peaks in magnetic resonance spectroscopy (MRS) measurements. The measurement of choline concentration by MRS has been shown to be elevated in breast cancers and can potentially give an early indication of response to treatment for primary breast cancers [5-7]. Breast MR spectroscopic techniques should realize improvements at the higher field strengths because of the greater spectral resolution that can be achieved. With the installation of larger numbers of 3T magnet systems, the impact of field strength on breast MRI performance may become more apparent.

Regardless of field strength, breast MRI should be performed using a dedicated breast radiofrequency coil. Most breast coils use multi-coil phased arrays with geometric designs optimized for bilateral imaging of the breasts, chest wall and axilla. While 4-coil arrays have been most common to date, 8-channel coils have recently been introduced and 16-channel coils are expected to be available in the near future, with resulting signal-to-noise improvements.

Patient positioning

Breast imaging is performed most commonly with the patient in the prone position, to minimize motion artifacts that can arise from respiration. Patients can enter the magnet feet first or head first; however, feet first entry can often be helpful in reducing claustrophobia. Because the patient must lie on top of the breast coil, which extends 6-8 inches above the patient table, space inside the magnet bore is even more restricted than with supine exams and thus patient comfort is an issue. Patients may find it more comfortable to raise their arms above their heads, with their head turned to one side. If an automatic injector is not used, access to the site of injection may need to be considered. Because of the need to minimize patient motion between scans, it is important that patients are comfortable enough to remain in the same position for the duration of the breast exam. The position of the breast in the coil should also be checked to see that the breast is as deep and as centered in the coil as possible, with the nipple facing straight down. Consistent positioning is especially important when serial studies need to be compared.

Light breast compression can be applied to immobilize the breast. Motion during the scan can cause blurring and other artifacts; motion between scans can cause mis-registration between pre-contrast and post-contrast images, which can make interpretation more difficult, particularly if subtraction methods are used to create enhancement-only images. Compression should be only minimal however, since strong compression can affect the kinetics of contrast enhancement by impeding the leakage of contrast into the tumor, potentially leading to false negative findings. This effect of compression should be taken into account when re-localizing a lesion for MR-guided biopsy, when stronger compression is likely to be used.

Contrast administration

For cancer detection, breast MRI is performed using a gadolinium-based contrast agent and T1-weighted imaging technique. Non-contrast imaging of the breast does not have adequate sensitivity or specificity and is not recommended for evaluation of breast cancer. Breast cancers are identified on the basis of significant early increase in signal intensity following intravenous injection of contrast agent. Clinically-available gadolinium-based contrast agents are used in combination with T1-weighted imaging methods, most commonly using a single dose of 0.1 mmol/kg body weight. Interpretation of breast MR images is largely based on the magnitude, speed and morphology of signal enhancement following injection. Thus it is critical that contrast injection be performed in a consistent manner from study to study. The use of a power injector can help ensure consistency and should be used if available. Injection can be performed as a bolus or infusion. Infusion rates in the range of 1-2 ml/sec are common. Unsuccessful or incomplete injections should be noted and taken into account by the interpreting radiologist. It may be necessary to recall the patient on another day for a repeat exam if the contrast injection was inadequate.

Pulse sequence techniques

A number of factors must be taken into account in choosing parameters of the T1-weighted pulse sequence for the contrast-enhanced study. In general, the choices involve making trade-offs between spatial resolution, temporal resolution, signal-to-noise, and whether active fat-suppression is used. The limiting factor for breast MRI is the need to acquire images within the first few minutes following the injection of contrast agent, before enhancement in the tumor and surrounding normal parenchymal tissue equilibrate. Small molecular weight agents such as the gadolinium contrast agents used for MRI will leak from the intravascular compartments into tissue. The detection of breast cancers relies on capturing the image soon after injection, when leakage in malignant tissue is still much greater than in normal tissue, because of its pathologic microvasculature. In general, one or more post-contrast image sets must be acquired within 2 minutes of contrast injection to sample the peak enhancement of breast malignancies. With longer times, contrast between malignant and normal breast tissue may be compromised. Thus, the selection of pulse sequence parameters, such as the matrix size, field-of-view (FOV), number of slices, and incorporation of active fat suppression, must take into account the need to keep total scan time on the order of several minutes or less. Dynamic techniques to measure pharmacokinetic parameters have more stringent requirements for temporal resolution, as described in the next section.

Gadolinium shortens the T1 value of tissue in proportion to its concentration, and a T1-weighted pulse sequence is used to maximize its signal-enhancing effect. 3D gradient echo techniques, which can provide greater spatial resolution than 2D techniques, are being used increasingly for breast MRI because of technology advances over the past decade that allow 3D acquisitions to be performed in under 2 minutes. The choice of image orientation (transaxial, sagittal, coronal) is largely based on radiologist preference. However, in any acquisition orientation, the phase encoding direction should be chosen to minimize image degradation due to motion artifact. For axial and sagittal scans, the anterior/posterior direction should be used for frequency-encoding, with the phase encoding in the left-right and inferior-superior directions, respectively.

While bilateral evaluation is often desirable or essential as for a screening exam, higher spatial resolution can be obtained in a unilateral exam. For a fixed matrix size (i.e., 256 x 256), in-plane spatial resolution is determined by the field-of-view chosen. Thus, a large, axial FOV prescribed to include both breasts, will have lower spatial resolution than an FOV prescribed to encompass one breast only. The number of slices chosen for a 3D scan will have a direct impact on scan time. In order to insure adequate coverage of one or both breasts, adjustments have to be made to the number of slices, slice thickness or both, at the time the scan is prescribed.

It is important to emphasize that some imaging parameters are selected at the time of scan prescription to optimize for a specific patient or type of exam (i.e., screening, staging). Imaging methods such as dynamic contrast-enhanced

(DCE) MRI, for which quantitative measurements of signal intensity changes will be used as the basis for diagnosis, require that data acquisition be performed according to a pre-defined protocol, and it is important to maintain consistency and to record when deviations to the protocol have occurred. For DCE-MRI, it is particularly important to adhere to timing requirements for the sequential scans acquired following contrast injection.

Dynamic contrast-enhanced MRI (DCE-MRI)

The classification 'dynamic' contrast-enhanced (DCE) MRI refers to techniques with sufficient temporal resolution to evaluate the time course of contrast uptake and washout in tumors, generally 1 minute or less. The temporal pattern of enhancement can be assessed visually by categorizing the enhancement as gradual, sustained or demonstrating washout. Quantitative measurements can be made by plotting a curve of signal intensity versus time and measuring empiric parameters such as the peak increase in signal intensity, the area under the curve (AUC) or the early-to-late signal enhancement ratio (SER). Physiologically relevant estimates of the transfer function k_{ep} and fractional plasma volume, fPV can be made by fitting the signal intensity changes to a pharmacokinetic model of the leakage of contrast agent from the intravascular space to the extravascular-extracellular space. For pharmacokinetic modeling, tissue T1 values and estimates of the arterial input function are needed [8, 9]. While quantitative methods can more precisely characterize the temporal pattern of enhancement, they require computer post-processing.

Several features of the contrast enhancement pattern have been associated with breast malignancies, including speculated borders, rim enhancement and contrast washout and a number of studies have used these features to discriminate benign and malignant breast lesions [10-16].

Parallel imaging techniques

Parallel imaging is an advance in magnetic resonance imaging technology that increases imaging speed by taking advantage of the different sensitivity profiles of the multiple coils used in a multi-coil array, such as the breast coil. Fewer k-space lines are acquired and sophisticated image reconstruction algorithms are used to resolve phase-wrap and combine the data from the individual coils into a single image. The scan time is reduced by a factor of R, where R is the number of individual coil elements. For breast imaging, sagittal images of both breasts can be performed in the same time as a unilateral exam. Alternatively, bilateral axial or coronal images can be obtained in shorter times. There is a signal-to-noise penalty associated with the time reduction. However, with newer, multi-channel phased array breast coils excellent image quality can still be obtained.

Fat-suppression

Fatty tissue will appear much brighter than fibroglandular tissue on both T1 and T2 weighted images, making it difficult to discern differences in signal intensity within fibroglandular tissue. To improve the ability to discriminate signal

differences in the fibroglandular tissue, fat-suppression is often used. Fat suppression can be actively imposed using chemical saturation of the fat signal, or conversely, selective excitation of the water signal. These strategies, which involve the use of special rf pulses as part of the pulse sequence, generally result in lengthened scan time. The uniformity of fat-suppression can also be compromised by inhomogeneities in the magnetic field, resulting in areas of the image where fat-suppression fails, and occasionally causing erroneous suppression of the water signal instead. The quality of active fat-suppression can be maximized by performing a manual gradient shimming procedure prior to the start of the scan. If localized fat-suppression failure still occurs, the images should be evaluated to determine whether lesion conspicuity is likely to be adversely affected. If so, slight adjustment to the center frequency setting (± 50 Hz) can be made to shift the spatial location of the fat-suppression failure.

Fat-suppression can also be effectively achieved using image subtraction, without incurring any increase in scan time. Following the imaging exam, pre- and post-contrast enhanced images are subtracted to produce an image of the enhanced areas of tissue only. The subtracted images are very useful for highlighting enhancing structures, but can artificially create bright areas when spatial mis-registration occurs because positioning of the breast has changed between the pre- and post-contrast scans. While the subtracted images are very informative about areas of tissue that have enhanced, non-enhancing tissue does not appear and information about the surrounding tissue structures, including the chest wall, cysts and surgical cavities is not provided.

Image post-processing

3D rendering methods using post-processing techniques such as the maximum intensity projection (MIP) are useful for visualizing the shape and location of enhancing lesions relative to the nipple, skin and chest wall. MIPs, which are used routinely in magnetic resonance angiography (MRA) to visualize vascular structures, can be created from the individual post-contrast data sets, or from a subtracted data set, using software provided on most MRI scanner as part of the vascular package. Other rendering techniques, such as 3D surfaces or cut-away views, are available as part of post-processing software packages offered commercially or as freeware. There are also many varieties of software packages that can be used to numerically analyze contrast-enhanced MR images, producing parametric maps of quantitative variables such as the pharmacokinetic constants or empiric variables such as area under the enhancement curve (AUC), time-to-peak enhancement or signal enhancement ratio (SER).

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